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Chaetopterid Polychaetes from Okinawa Island, Japan, with Notes on the Feeding Behaviour of *Spiochaetopterus costarum costarum*

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Abstract Occurrence of four chaetopterid polychaetes, namely *Phyllochaetopterus herdmani* Willey, *P. verrilli* Treadwell, *Mesochaetopterus sagittarius* (Claparède), and *Spiochaetopterus costarum costarum* (Claparède), are reported from the sandy bottom of Sesoko Island, Okinawa, Japan. Setal morphology and several body characters are described based on the scanning electron microscopical observations. Among them, *Phyllochaetopterus herdmani*, *P. verrilli* and *S. costarum costarum* are new to Japan. Feeding behavior of *S. costarum costarum* was studied during the rearing experiments using glass tubes. This species performs mucous-bag feeding by employing foliaceous notopodia and a cupule located at the first setiger of middle body region.

Key words : chaetopterid polychaete, Okinawa, taxonomy, mucous bag, feeding behaviour

Introduction

Chaetopterid polychaetes are known to feed using mucous bags that become loaded with food and are swallowed then replaced with new one (Brown, 1975, 1977). The minute aggregating chaetopterid, *Mesochaetopterus sagittarius*, is well known in Japanese waters, and other 7 chaetopterids, *Chaetopterus cautus*, *C. kagosimensis*, *C. longipes*, *Phyllochaetopterus prolifica*, *P. aciculigerus*, *Mesochaetopterus japonica*, *Spiochaetopterus costarum okudai*, are known in Japan up to now. Among them, only three chaetopterids, *Chaetopterus cautus*, *C. longipes*, and *Phyllochaetopterus aciculigerus*, have been reported from Okinawan seashores so far (Uchida, 1990; Nishi, 1996). During the present study, we report the presence of 4 species of chaetopterid polychaetes from Sesoko Island, Okinawa, southeastern Japan. Two species of *Phyllochaetopterus*, *P. herdmani* and *P. verrilli*, form sand-covered fragile tube partly attached to stone or coral skeleton, and *Spiochaetopterus costarum costarum* and *Mesochaetopterus sagittarius* form membranous (chitinous?) tube vertically embedded in the sand. Among them, 2 species and one subspecies are new to Japan, and all 4 are new to Okinawa.

On the taxonomy of chaetopterid polychaetes, the setal morphology, particularly that of the cutting or tearing setae of the 4th setiger are used for identification to the species level (Scheltema, 1974; Bhaud, 1978). We observed the setae with the scanning electron microscope (SEM) to identify the species. Gitay (1963) segregated *Spiochaetopterus costarum* into 5 subspecies based on several characters, such as, the number of segments of the middle region, presence of bilobed or unilobed parapodia, presence of eyes, etc. So we identified *Spiochaetopterus costarum* to the subspecies level.

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As to feeding behavior of minute chaetopterid species, most of the observations available were made in species such as *Mesochaetopterus rickettsii*, *M. taylori*, and *Phyllochaetopterus prolifera* (MacGinitie & MacGinitie, 1949; Abbott & Reish, 1980; Barnes, 1965; Sendall et al., 1995). Barnes (1964) reported in detail the feeding behavior in *Spiochaetopterus oculatus*. Various polychaete biologists suggested the uniqueness of the mode of feeding of chaetopterid species but ecological and behavioral studies on this aspect are few. Accordingly, we have studied the feeding behavior of a small chaetopterid which occurred abundantly in the sandy bottom of Sesoko Island, Okinawa.

Study Sites

The study sites Zampa Cape, Maeda Cape, and Sesoko Island lie around the Okinawa Island, northwestern Japan. In these study sites, undersurfaces of stones at selected sand shore or moat at 1-2 m depth were surveyed carefully for presence of minute tubes of polychaetes through skin-diving or scuba-diving. Surveys were conducted in the summer 1990 and 1991, and the spring to summer 1992. Additional samplings were also made during February to April, 1993.

Methods

While *Phyllochaetopterus herdmani* and *P. verrilli* were collected from the undersurface of stones using a spatula, *Spiochaetopterus costarum costarum* and *Mesochaetopterus sagittarius* were collected by digging in the sandy bottom usually to a depth of 10 to 20 cm. Tubes which were damaged during the collection were not used for the laboratory studies.

After the observation of tube dwelling behavior of these worms through a dissecting microscope, worms were denuded of their tubes, fixed in 2% glutaraldehyde, and postfixed with osmium tetroxide. Then they are dehydrated through a graded alcohol series, dried using a critical point drier, and coated with gold-palladium. Final preparations were viewed with a SEM (Hitachi, S-530).

Two to 10 worms of each species were observed through dissecting and compound microscope, and 1 to 4 worms of each species with SEM. Some specimens are preserved in alcohol and deposited in the Natural History Museum and Institute, Chiba (*Spiochaetopterus costarum costarum*: CBM-ZW 69 (1 worm), 70 (3 worms), 71 (13 worms), 72 (14 worms), 73 (13 worms), 74 (16 worms), 75 (10 worms); *Mesochaetopterus sagittarius*: CBM-ZW 76 (1 worm), 77 (2 worms); *Phyllochaetopterus herdmani*: CBM-ZW 78 (1 worm); *P. verrilli*: CBM-ZW 79 (2 worms).

Observations of the feeding behavior of *S. costarum costarum*

Samples were collected from 0.5 to 1 m depth of the sandy moat of Sesoko Beach, Sesoko Island, Okinawa, during February to June, 1993. Worms were removed from their tubes and placed in glass capillary tubes. Transfer was done by sucking the worm from the posterior end of the tube with a pipette, and breaking off the tip of the pipette which contained the worm using a spatule. The glass tube containing the worm was kept in a horizontal position on the sandy bottom of a plastic container.

Observations on feeding behavior were made with the help of a binocular microscope and a dissecting microscope. *S. costarum costarum* ranged in length from 3 to 6 mm and in width from 0.5 to 1 mm. *M. sagittarius* is similar in size to *S. costarum costarum*, but can be easily identified by their body characters, i.e., the presence of white ventral shield.

Results

Phyllochaetopterus herdmani Willey, 1905
(Fig. 1A,B ; Fig. 2A-I)

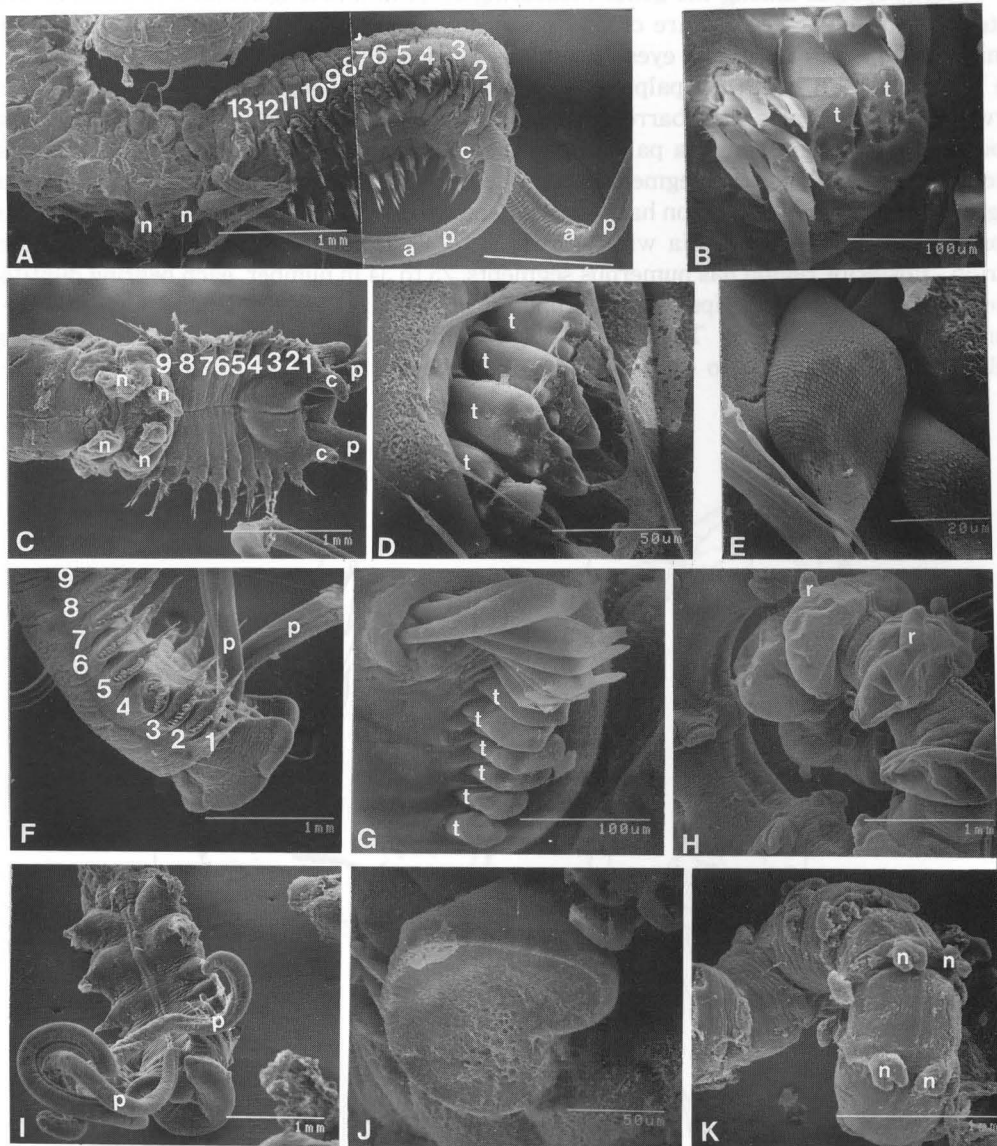


Fig. 1. Scanning electron micrographs of 4 chaetopterid polychaetes. A & B, *Phyllochaetopterus herdmani*; A, anterior and middle region; B, 4th setiger shows 2 cutting setae and fascicle of 7 lanceolate setae; C, D, & E, *Phyllochaetopterus verrilli*; C, dorsal side showing notopodia; D, 4th setiger; E, oar-like setae; F, G, & H, *Mesochaetopterus sagittaris*; F, anterior region; G, 4th setiger; H, posterior region; I, J, & K, *Spiochaetopterus costarum*; I, Anterior region; J, cutting seta; K, posterior region with bilobed notopodial lobes. a, antennae; c, cirri; n, notopodia; r, projection on the notopodial lobe; p, palp, t, cutting setae. Numbers in A, C, and F show the order of segments in anterior region.

Phyllochaetopterus herdmani Willey, 1905; Day, 1967.

A large species among the genus measuring 50–80 mm in length and 1 to 2 mm in width. Anterior and middle regions are cream, posterior region is green or greenish black. Prostomium, with a pair of minute eyes, is small and reduced (Fig. 1A, Fig. 2A). Tentacular cirri are long, located beneath the palp, and not tapered. Buccal segment is large, truncate and curving upwards. Palps were barred and long reaching to the middle of posterior region, and about 60 rings were found in a palp. Granular shield is absent. There are 13 segments in anterior regions (Table 1). Segment 4 has 2 to 3 stout setae obliquely truncate at the ends (Fig. 1B, Fig. 2B). Middle region has two segments with elongate bilobed notopodia, and large expanded wing-like neuropodia with uncini (30 to 40 in number) along the whole external margin. Posterior region has numerous segments, 25 to 34 in number, each bearing digitiform notopodia with knobbed tips, and neuropodia are square shape. Uncini have twelve to fourteen teeth (Fig. 2G,H). The tube is fragile and thickly encrusted with sand-grains and shell fragments, almost 3 to 4 times longer than the worms.

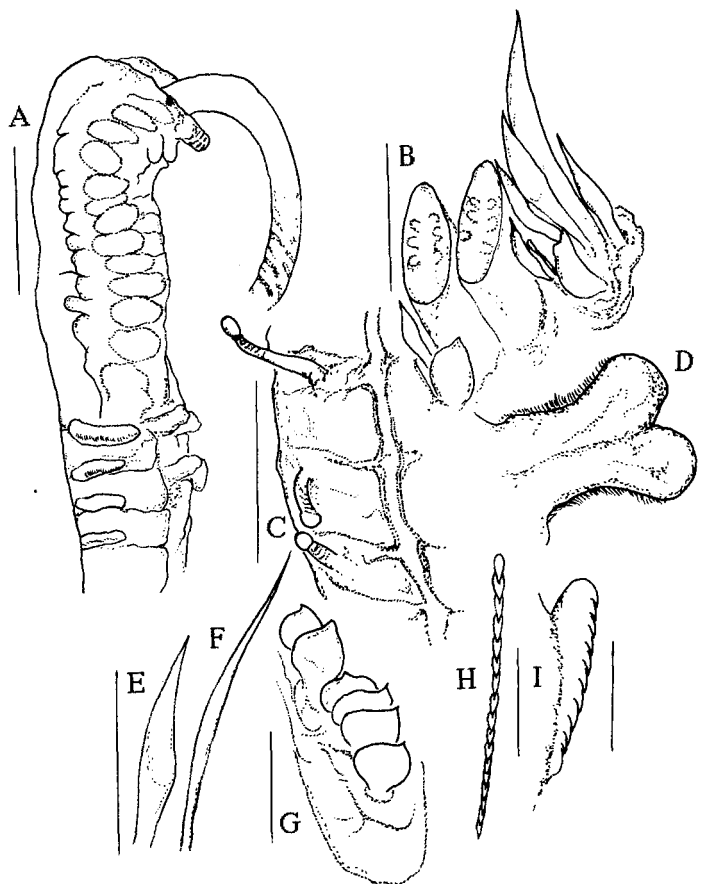


Fig. 2. *Phyllochaetopterus herdmani*. A, anterior and middle region; B, two cutting setae and fascicle of lanceolate setae of 4th setiger; C, projections on the posterior region; D, bilobed notopodia; E & F, bordered setae of anterior region; G, oar-like setae; H & I, uncini. Scale; 1 mm (A), 500 μ m (C, D), 100 μ m (B, E, F, G), 10 μ m (H, I).

Table 1. Number of setae (spc, specialized; bord, bordered; oar, oar like setae, see results) in anterior region of 4 chaetopterid polychaetes. P.h. *Phyllochaetopterus herdmani*; P.v. *Phyllochaetopterus verrilli*; M.s., *Mesochaetopterus sagittarius*; S.c., *Spiochaetopterus costarum costarum*

Setiger	P.h.			P.v.			M.s.			S.c.		
	spc	bord	oar	spc	bord	oar	spc	bord	oar	spc	bord	oar
1	0	7	3	0	4	9	0	4	0	0	4	3
2	0	6	10	0	2	13	0	7	10	0	3	3
3	0	5	12	0	1	15	0	4	14	0	3	4
4	2	2	9	4	0	9	7	0	7	1	4	2
5	0	3	10	0	1	15	0	5	14	0	3	5
6	0	4	10	0	2	15	0	2	14	0	6	7
7	0	6	8	0	3	15	0	2	15	0	2	8
8	0	5	10	0	3	15	0	2	13	0	4	6
9	0	4	10	0	3	14	0	2	14	0	3	5
10	0	4	8	0	3	14	0	2	13			
11	0	0	8									
12	0	0	8									
13	0	0	8									

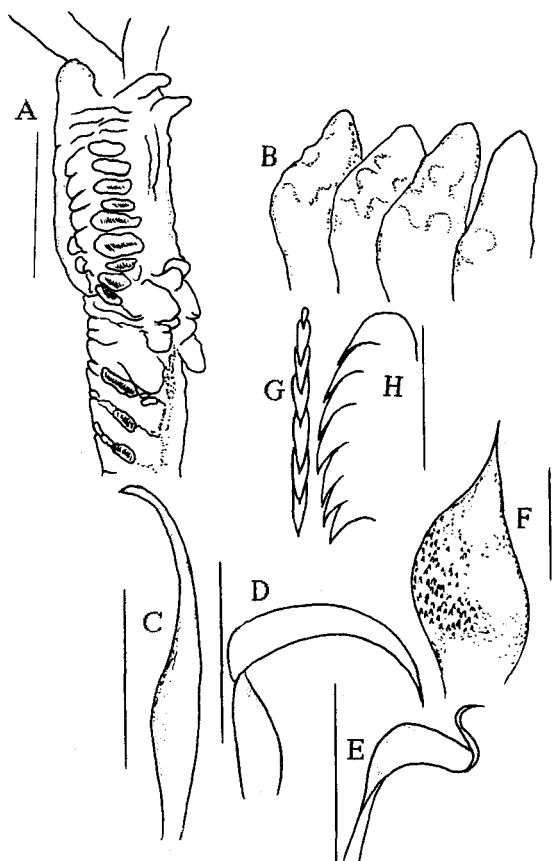


Fig. 3. *Phyllochaetopterus verrilli*. A, anterior and middle region; B, four cutting setae of 4th setiger; C, D, & E, bordered setae; F, oar-like setae; G & H, uncini. Scale; 1 mm (A), 50 μ m (C, D, E), 20 μ m (B, F, G, H).

***Phyllochaetopterus verrilli* Treadwell, 1964**

(Fig. 1C-E; Fig. 3A-H)

Phyllochaetopterus verrilli Treadwell, 1964; Bailey-Brock, 1987.*Phyllochaetopterus brevitentaculata* Hartmann-Schröder, 1965.

Body is 50 to 80 mm in length and 0.5 to 1 mm in width. Anterior and middle region were white or creamy white with posterior region black or dark green. Palps are long, reaching middle or posterior part of the posterior region. Eyes are absent. A pair of short cirri, 300 to 500 μ m long, are located beneath the palps. Anterior region is composed of 9 segments (Fig. 1C, Fig. 3A). The 4th setiger has 4 stout cutting setae (Fig. 1D, Fig. 3B) and 4 to 6 lanceolate setae (Fig. 3B, Table 1). Twisted, curved and bordered setae (Fig. 3C-E) are found on the all setigers in the anterior region except for the 4th setiger (Table 1). Middle region is composed of 2 segments bearing bilobed notopodia forming a mucous bag and neuropodia bearing a large number of uncini (30 to 40 in number) in one row. The cupule is absent. Between the bilobed notopodia, two distinct ciliary rows were observed. Neuropodia are bilobed each with 25 to 30 uncini. Each uncinus has 6 to 8 teeth (Fig. 3G,H). Tubes are covered with fine sand, shell debris or foraminiferans; they are 5 to 7 times the length of the body.

***Mesochaetopterus sagittarius* Claparède, 1868**

(Fig. 1F-H; Fig. 4A-H)

Mesochaetopterus sagittarius Claparède, 1868; Bailey-Brock, 1987.*Mesochaetopterus minuta* Potts, 1914.

Body measured about 10-20 mm long with more than 20 segments. Anterior and middle region were creamy white, posterior region was black, dark green or dark brown. Anterior region has nine to ten uniramous segments (Fig. 1F, Fig. 4A) with white ventral shield extending throughout the anterior segments. Prostomium is ovoid. Palps are long, not barred, and have a pair of eyes at their base. Fourth setiger has 6 to 8 modified setae bearing obliquely truncate and serrated tips (Fig. 1G; Fig. 4B,C) and 5 to 8 bordered setae. Notosetae of anterior region are lanceolate or bordered (Fig. 4D), oar-like (Fig. 4E), or foliaceous (Fig. 4H) like "*Apomatus*" setae of the Serpulidae. They are found in each setiger (Table 1). Middle region has two long segments, the first one of which had a pair of short notopodia close to the last part of the anterior region (Fig. 4A). The middle region is about the same length as the anterior region, 2 to 2.5 mm in length when observed under the SEM. The second segment has a pair of long strap-like notopodia and a posterior cupule (Fig. 4A). Neuropodia are bilobed and have a divided series of embedding uncini in number ranging from 25 to 30. Individual uncini (Fig. 4 F,G) has six to nine teeth. Posterior regions have 18-20 short segments each bearing two simple conical neuropodia having two pairs of uncinigerous tori containing 20 to 30 uncini. Notopodial lobes are flap-like with a dorsal pair of projections of 300-500 μ m in length (Fig. 1H). Tube is fragile and encrusted with sand or shell-debris, 10 to 20 cm in length and 1-3 mm in width. Animals are solitary (4 worms) or gregarious (2 colonies with 7 and 10 worms).

***Spiochaetopterus costarum costarum* (Claparède, 1868)**

(Fig. 1I-K, Fig. 5A-J)

Telepsavus costarum Claparède, 1868; Barnes, 1965.*Spiochaetopterus costarum costarum* Gitay, 1963.

Body is 40-60 mm long, slender and fragile. Anterior and middle regions are creamy

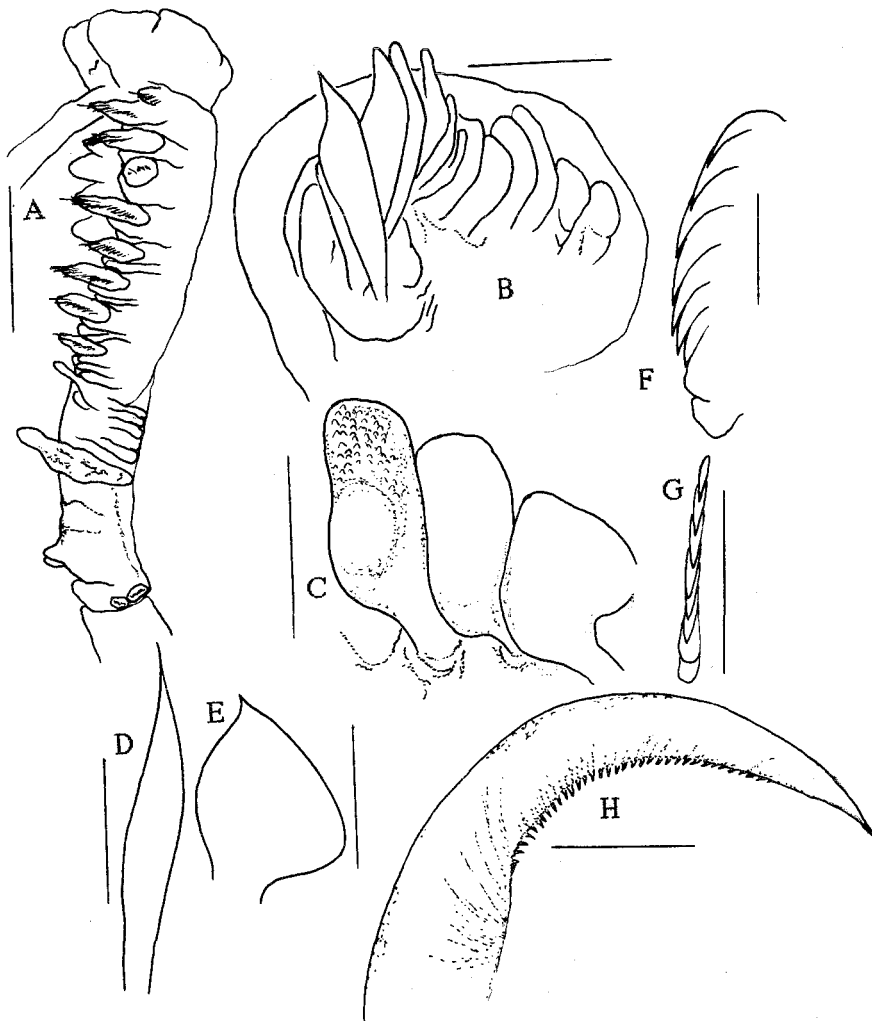


Fig. 4. *Mesochaetopterus sagittarius*. A, anterior and middle region; B, 4th setiger; C, three cutting setae; D & E, bordered and oar-like setae; F & G, uncini; H, twisted foliaceous seta. Scale; 1 mm (A), 100 μ m (B), 50 μ m (C, D, E), 20 μ m (F, G, H).

white and posterior region is brown or dark brown. Palps are long (Fig. 1I) and speckled with brown. Prostomium is ovoid and marked within the rim by a brownish band. A pair of eye-spots is located on the lateral side of the palps. Anterior region has nine setigers with a dark gland on the ventrum of setiger 7, preceding a white gland on setigers 8 and 9 (Fig. 5A). A pair of enlarged setae is present on the 4th setiger (Fig. 1J, Fig. 5B-D). The notosetae in the anterior region is bordered or lanceolate (Fig. 5G), or oar-like (Fig. 5H) in varying numbers (Table 1). Middle region has 18-24 segments, each bearing bilobed notopodia (Fig. 1K), lateral triangular branchiae and bilobed neuropodia with numerous uncini (15-30 in number). Each uncinus has 16-20 teeth (Fig. 5I, J). A cupule is present only in the first middle segment (Fig. 5A, E). A pair of lateral brown spots is present in the middle region of each segment except for the first one. The posterior region is short with segments bearing digitiform notopodia and neuropodia with pinnules (Fig. 1K, Fig. 5F). The tube is chitinous,

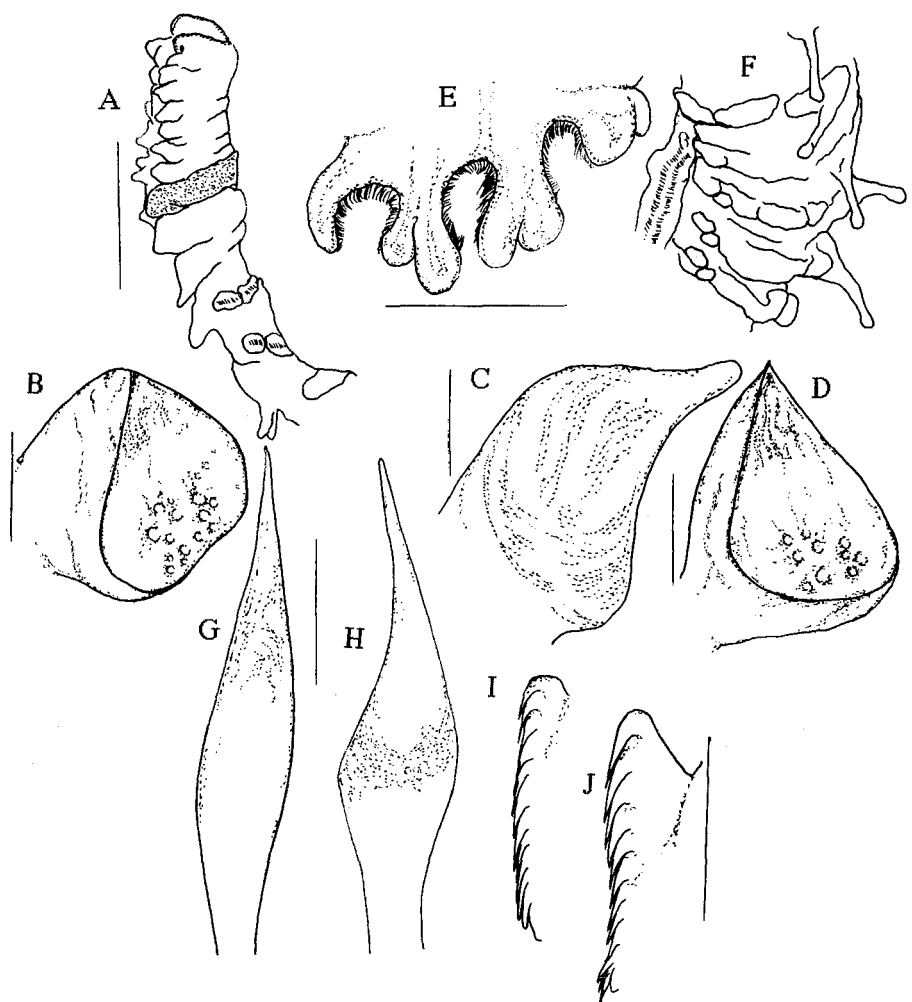


Fig. 5. *Spiochaetopterus costarum costarum*. A, anterior and middle region; B, C, & D, cutting setae of 4th setiger; E, lobed notopodia; F, posterior region; G & H, bordered and oar-like setae; I and J, uncini. Scale; 1 mm (A), 500 μ m (E, F), 50 μ m (B, C, D), 20 μ m (G, H), 10 μ m (I, J).

brown and ringed in 1 to 1.5 cm distances and partly translucent. Some branches were found in the tube, but only one worm was observed in a tube. Tube was longer than a worm, usually reaching 20 cm rarely over 30 cm. Worms are solitary.

Feeding behavior of *Spiochaetopterus costarum costarum*

S. costarum costarum produced water current which pass through a foliaceous notopodia producing mucous bag which is found in the second middle setiger (Fig. 6). The parapodia with branched foliaceous notopodium formed three ciliary rings, a mid-dorsal and two lateral ones. Only in the second setiger of middle region, a cupule appeared, then a mucous bag and a food ball could be formed in this setiger (Fig. 6). Other setigers lacked cupule and the food ball was not observed. Water current in this worm was produced by beating cilia and membranelles distributed on the ciliary rings. Between the first mid-dorsal ciliary ring and

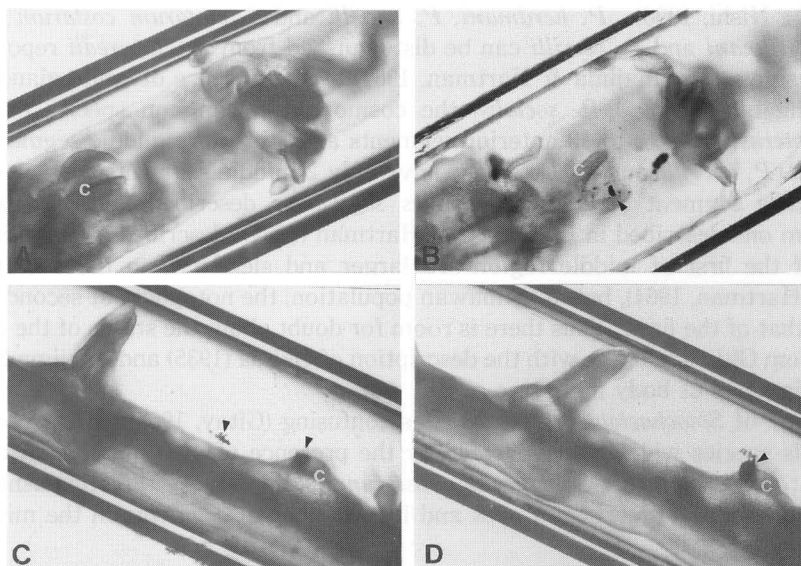


Fig. 6. Feeding behavior of *Spiochaetopterus costarum costarum*. A & B, dorsal side ; C & D, lateral side. Arrow shows mucous bag. c, cupule.

the cupule, a mucous bag was formed, followed by the formation of a food ball (Fig. 6D). When a food ball attained an adequate size, usually slightly larger than the width of the cupule, the ball was carried to the mouth along the mid-dorsal ciliary groove. The time required for the complete formation of mucous bag and food ball ranged from 30 seconds to 2 minutes, average 52 seconds, S.D. 32, in two worms. The food ball is then carried forward along the mid-dorsal ciliary groove. When the food ball passes through a ciliary ring, the two notopodia were separated slightly and were found to be inclined somewhat anteriorly. The ciliary beating continued even when they were not feeding.

This species also employed mucous string feeding during high particle concentration. Some mucous strings were observed simultaneously, and were not limited to the anterior segments of the middle body region. The mucous string was formed in the mid-dorsal ciliary rings, then rolled up by the activity of foliaceous notopodia during the movement of many rings at the anterior segments.

Palps have rarely functioned as feeding organs. Small masses of detritus or sand grains were carried into the mouth directly. Grain size of food particles varied from 100 to 300 μm , but the sand particles were later ejected as feces.

Feeding is the usual activity when the worm is stationary, however, the worm commonly inverts itself to form J-shape when they are fed, and the mucous strings are usually rolled up to the mouth by this behavior. When the worm inverted, they did not feed mucous directly. A mass of mucous strings was transported as in the case of the mucous ball through the fecal groove.

Discussion

In Japan, 3 *Chaetopterus* (*C. cautus*, *C. kagosimensis*, and *C. longipes*), 2 *Mesochaetopterus* (*M. japonicus* and *M. sagittarius*), 2 *Phyllochaetopterus* (*P. claparedii* and *P. aciculigerus*) and one *Spiochaetopterus*, *S. costarum okudai* (described as *Telepsavus costarum* Claparède; Okuda, 1935, p.94-98) are known (Izuka, 1919; Okuda, 1935; Imajima & Hartman, 1964;

Uchida, 1990; Nishi, 1996). *P. herdmani*, *P. verrilli* and *S. costarum costarum* are new to Japan. *P. herdmani* and *P. verrilli* can be distinguished from *P. claparedii* reported earlier from Japanese waters (Imajima & Hartman, 1964) by the absence of white glandular shield and preceding black ring. *P. socialis*, the cosmopolitan common species of the genus *Phyllochaetopterus*, have 12 to 13 anterior segments and 7 or more middle segments (Bailey-Brock, 1987). *P. verrilli* and *P. herdmani* have only 2 middle segments.

The middle segment of *Mesochaetopterus sagittarius* described in this paper slightly different from one described in Imajima and Hartman (1964) (described as *M. minuta*). The notopodia of the first of middle region are larger and slender than those of the second (Imajima & Hartman, 1964), but in Okinawan population, the notopodia of second segment is longer than that of the first. Thus there is room for doubt about the status of the species, but specimens from Okinawa agree with the description of Okuda (1935) and Imajima & Hartman (1964) in main parts of body and setae.

Taxonomy of *Spiochaetopterus costarum* is confusing (Gitay, 1963). Five subspecies are known in this species which are separated by the presence of eyes, number of cupula, etc. (Gitay, 1963; Gilbert, 1986). *S. costarum costarum* in this study is distinguished from *S. costarum okudai* by the presence of eyes and less number of segments in the middle region (Gitay, 1963).

Chaetopterid tubes are usually buried in sandy bottom, and are not gregarious in habitat. Barnes (1975) studied the feeding behavior in *Spiochaetopterus* spp. and *P. prolifica*. Gitay (1963) studied the feeding method of *Spiochaetopterus* spp. and now it might be used in the taxonomy. *S. costarum costarum* is similar to *S. oculatus* in many aspects of feeding behavior and its tubicolous nature. But many characters differ between these species. In *S. costarum costarum*, a single mucous bag is produced by the first middle segments, while in *S. oculatus*, as many as 13 bags were simultaneously formed. The latter species performed only mucous bag feeding, while the former species did three distinct feeding methods, namely, mucous-bag feeding, mucous string feeding and trapping of particles by the palps.

S. costarum costarum has a single combination of foliaceous notopodia and a cupule, thereby producing only a single mucous bag. *M. sagittaris*, sympatrically occurring at the sampling site, also had only a single combination of the above two and producing only one mucous bag (personal observation of E. Nishi).

S. costarum costarum had 12 to 18 pairs of foliaceous notopodia which forms three ciliary rings. Except for the first segment, all other notopodia perform mucous string feeding. The mucous string feeding was known in *Phyllochaetopterus* and *Mesochaetopterus*, but this is the first record of mucous string feeding in the genus *Spiochaetopterus*.

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